Clean Automotive Technology…
Innovation that Works

AFFORDABLE Advanced Technologies

presented to

FACA Meeting

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Meeting the Challenge of High Efficiency and Low Emissions

Revolutionary Drivetrains

Revolutionary Engines

Ultra-Clean & Ultra-Efficient Vehicles

2

Big Break-Throughs Leading to Mid-term Solutions

Clean, fuel-efficient and cost-efficient Solutions that can make a difference!

Clean Diesel

- shows viability to meet engine-out NOx for Tier 2 (Bin 5) and heavy-duty 2010 standards without NOx aftertreatment
- research suggests it may be competitive with other alternatives for meeting future diesel standards
- Light and Heavy duty engines

Series Hydraulic Hybrid Vehicles

- Urban Delivery Vehicles (Class 5 & 6)
- Sport Utility Vehicles

Patented EPA Technologies

3

More Engine Break-Throughs ...

HCCI Combustion

- 4 cylinder engine working, installed in truck
- Virtually "no" NOx or PM emissions
- Diesel like efficiency from gasoline
- Excellent engine for a series hybrid
- Paper in March 2004 SAE Congress

Free-Piston Engine

- Great efficiency -Hydraulic power directly from engine
- Clean 4-stroke cycle or High Power 2-stroke cycle
- Capable of Clean Diesel or HCCI combustion
- High Reliability/Low Cost potential: fewer moving parts

Patented EPA Technologies

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More Emerging Engine Technologies...

Ethanol-Value

- Diesel-like efficiency, low GHG
- Payback analysis – low cost fuel (E30) still achieves high fuel economy
- Ready for fleet demonstration

Variable Displacement Engine

- Allows optimum high efficiency use of a small displacement engine while retaining the option for sustained high power when needed

Variable Compression Engine

- Allows low power, very efficient engines to also provide high power performance

Patented EPA Technologies

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Controlling Diesel Engine-out NOx...

Air Management

- controls peak combustion temperature with boost & EGR (low NOx)

Fuel and Combustion Management

- promotes fast combustion utilizing advanced fuel injection systems for performance, good efficiency, and low smoke/PM

Conventional Aftertreatment

- reduces PM, HC & CO to the level of the standards

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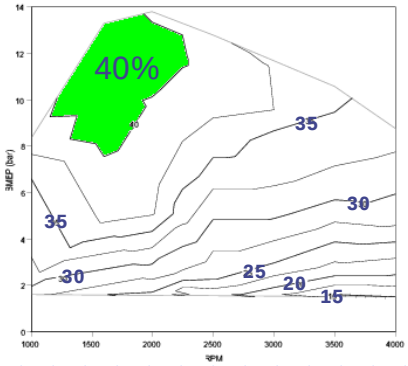
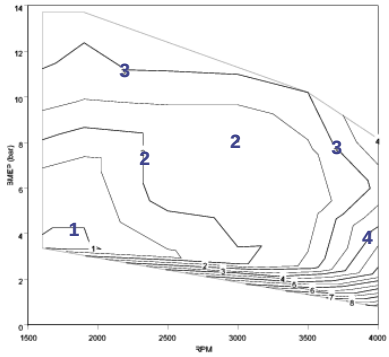
Diesel Combustion in a Current 1.9L Engine…

% Brake Thermal Efficiency



NOx Engine Out (g/hp-hr)



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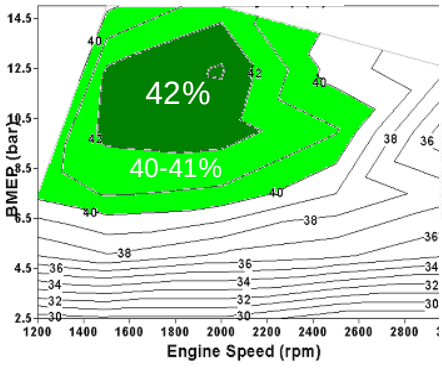
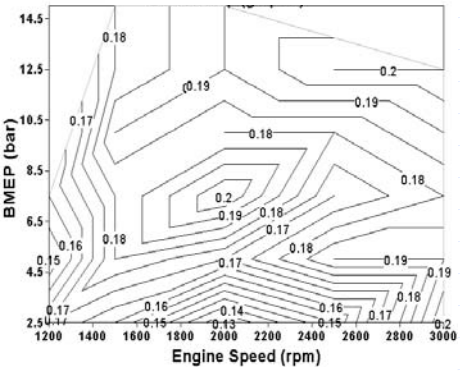
EPA Clean Diesel Combustion (1.9L Multi-Cylinder Evaluation)

Engine Brake Efficiency (%)



$P_{exhaust} = P_{input} + .1$ Bar

Brake Specific NOx (g/hp-hr)



NOx below .2 everywhere

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Historic EPA Hydraulic Hybrid Test Chassis

- ✓ Full Series Hydraulic Hybrid
- ✓ 80+ mpg combined city/highway mpg
- ✓ ~8 seconds 0-60 acceleration time
- ✓ No need for expensive lightweight materials (test weight 3800 lb)

- ✓ 25 patents, 25 more pending
- ✓ Led to 3 industry partners – Ford, Eaton, Parker-Hannifin
- ✓ Lead the way for subsequent demonstration vehicles

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Current EPA Demonstration of Hydraulic Hybrid Vehicles

1. **Class 5 Delivery Truck**
   - Launch Assist (parallel) Hydraulic Hybrid
   - Diesel Engine
   - Package suitable for retrofits
2. **Sport Utility Vehicle**
   - Full (series) Hydraulic Hybrid
   - Diesel Engine
3. **Class 6 Urban Package Delivery Vehicle**
   - Full (series) Hydraulic Hybrid
   - Diesel Engine

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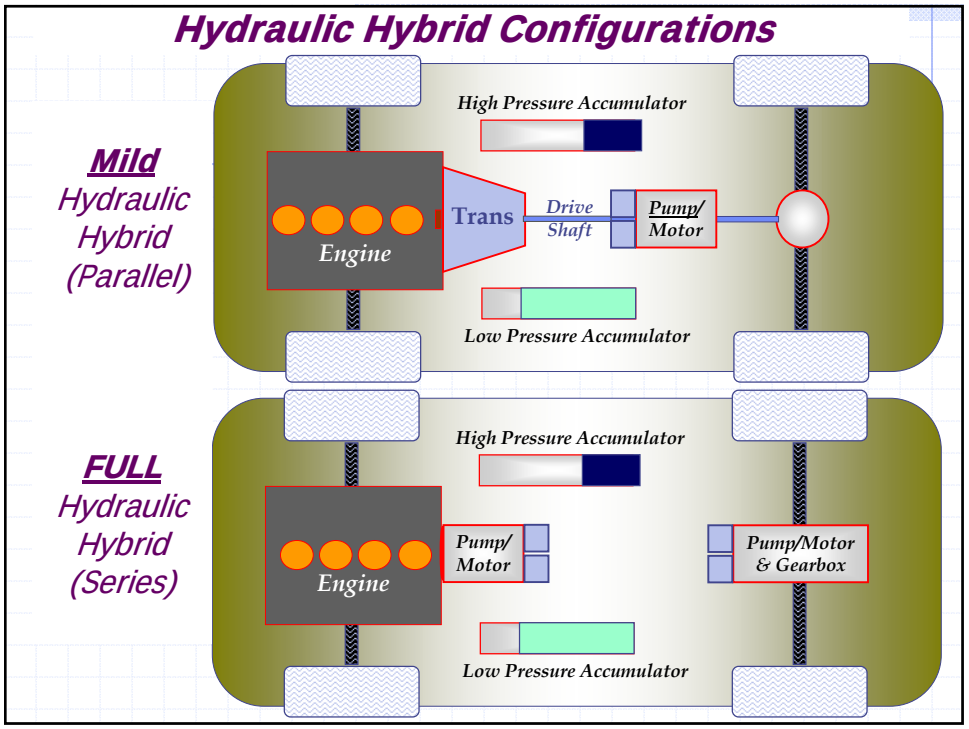
Hydraulic Hybrid Configurations



Urban Delivery Truck - Hybrids through Retrofitting

Hybrid Assist Hydraulic Hybrid

- Demonstrates the ease of retrofitting trucks with hydraulic hybrid technology
- Shows ability to get low hanging fruit (20-30% mpg improvement)
- Gold award for mpg improvement and Silver award for performance at the *2003 Michelin Bibendum Challenge*

EPA's F-550 fleet retrofit demonstration vehicle with hydraulic launch assist.

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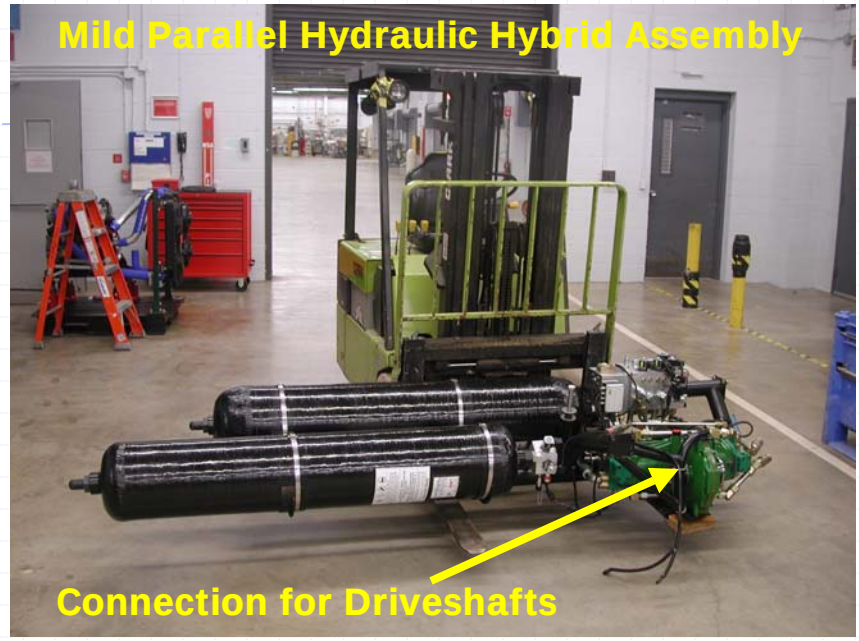
Mild Parallel Hydraulic Hybrid Assembly



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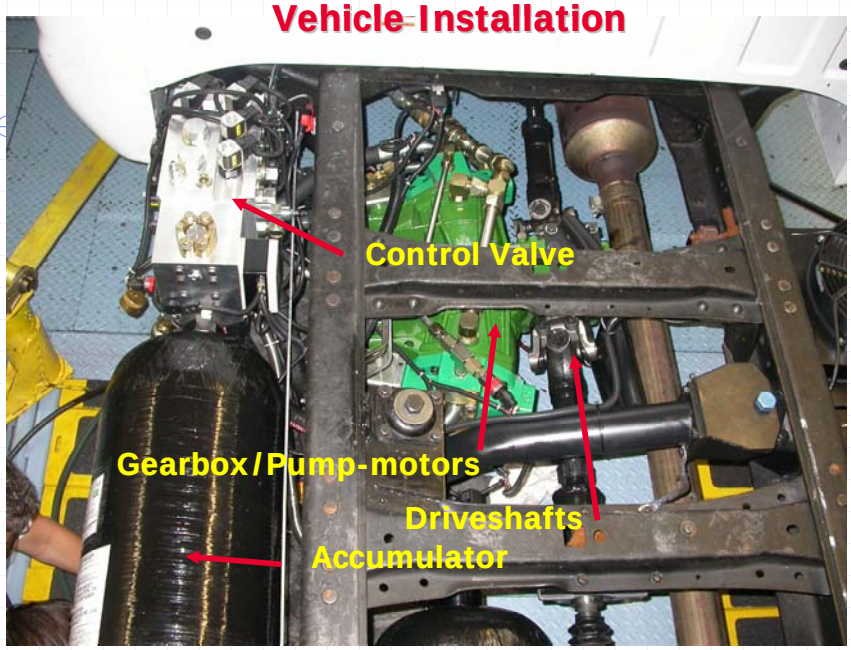
Vehicle Installation



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Full Hydraulic Hybrid SUV

- Full integrated hydraulic hybrid, diesel engine, clean packaging, cost effective, targets 85% mpg improvement
- Excellent 1-3 year payback for consumer
- Best configuration to communicate a vision of production potential

Showcasing the full use of hydraulics in a Ford Expedition.

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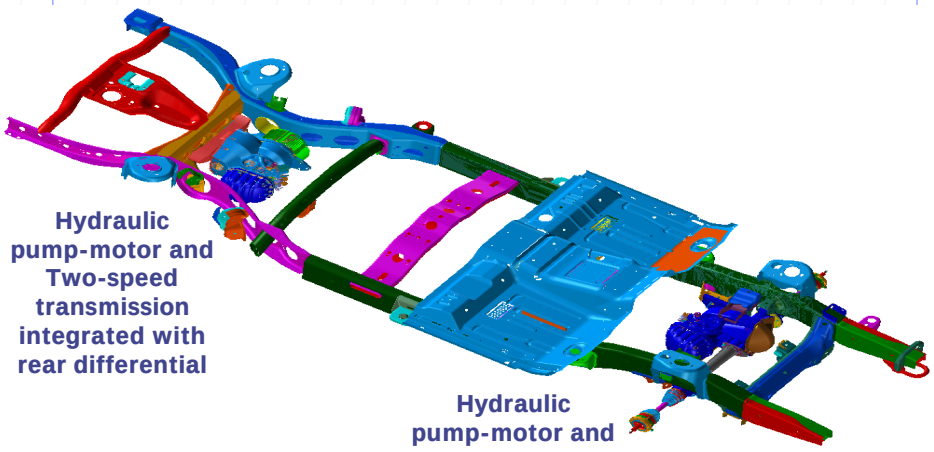
Innovative Integrated Packaging



Hydraulic pump-motor and Two-speed transmission integrated with rear differential

Hydraulic pump-motor and parking pall integrated with front differential

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Integrated Design…

View from Rear

Engine Pump

Integrated Front Drive

Integrated Rear Drive w/ 2-speed Trans

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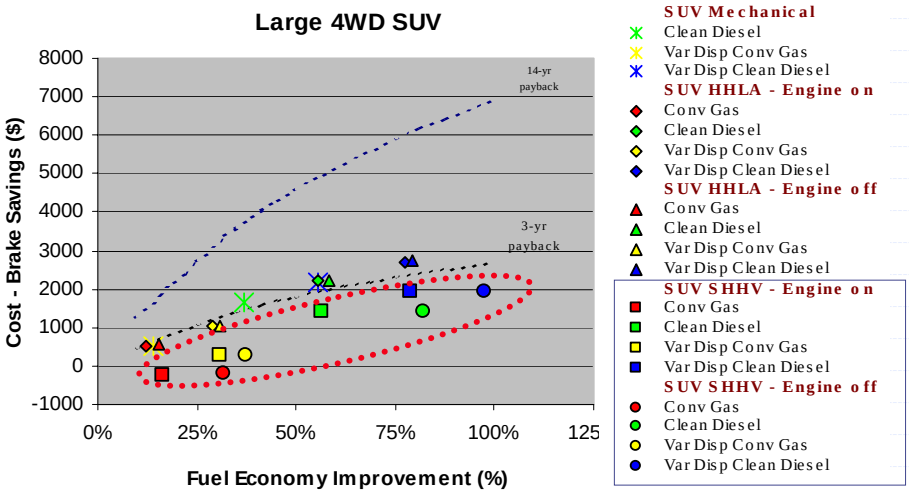
Comparison of SUV Technologies…

Consumer Payback



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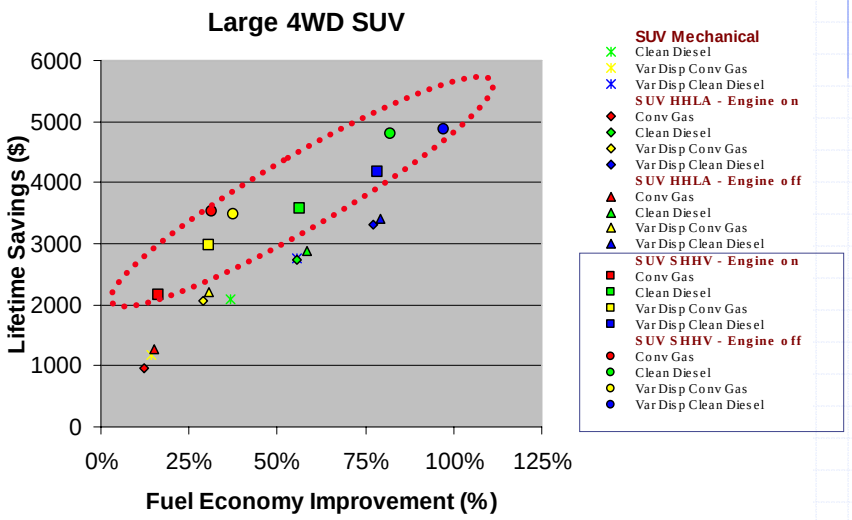
Comparison of SUV Technologies...
Net Consumer Lifetime Savings



For More Information

Progress Report on Clean and Efficient Automotive Technologies Under Development at EPA

Interim Technical Report

January 2004

www.epa.gov/otaq/technology.htm

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Urban Delivery Vehicle - *Full Hydraulic Hybrid*

- First-ever full integrated hydraulic hybrid delivery vehicle, targets 70% mpg improvement in city driving
- 2-year payback has attracted serious attention from fleets
- Partnership involving EPA, Eaton, UPS, OEM & Army
- Announcement later this year

Showcasing full hydraulic hybrid systems in an Urban Delivery Vehicle.

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Hybrids and Competing Technologies

Our Conclusions---

Hydraulic hybrid vehicles are a promising near-future powertrain with important consumer attributes such as:

- 1 to 3 year investment payback
- significant reduction in lifetime operating expenses
- improved vehicle performance

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